

An Empirical Study on the Capacity of Bottlenecks on the Basic Suburban Expressway Sections in Japan

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ABSTRACT

This paper briefly reports the results of analyses on traffic flow data, which were recorded every five minutes by vehicle detectors for approximately one year at bottleneck sections (mainly sags and tunnel entrances) on suburban expressways in Japan.

The analyses include the estimation of traffic volume just before the occurrence of congestion which can be considered close to the possible capacity of the bottleneck; and the factor analysis on the relationship between traffic volume and the number of lanes, the width of left side shoulder, the longitudinal gradient, the percentage of heavy vehicles, and the day of the week. The results of the factor analysis shows that capacity per lane increases more than proportionally to the increment of the number of lanes; that the effects of the width of left side shoulder and the percentage of heavy vehicles is not prominent; and that traffic volume just before congestion tends to vary depending on the day of the week.

The above results are found by the analyses which were carried out based on the conditions; that there are a lot of tunnels and sags in Japan due to its topographical features; that the maximum number of lanes of expressways is three for each direction; that traffic congestion more frequently occurs in Japan compared with other countries. These findings are expected to give useful suggestions also for studies in foreign countries.

1. PREFACE

Expressways in Japan, totaling 6,452 km in service as of April 1999, are an indispensable infrastructure and have been playing a pivotal role in social and economical activities. However, with the economic growth and the variation of life-styles, congestion is frequently caused mainly around major cities due to the rapid increase of traffic demand, posing a serious social problem.

The definition of traffic congestion on expressways in Japan is a condition where the length of the queue of vehicles, which travel at a low speed of less than 40 km/h or repeat stop and go, is longer than 1 km, and the duration of such a state is more than 15 minutes. The number of occurrence of traffic congestion recorded during the past 10 years is shown

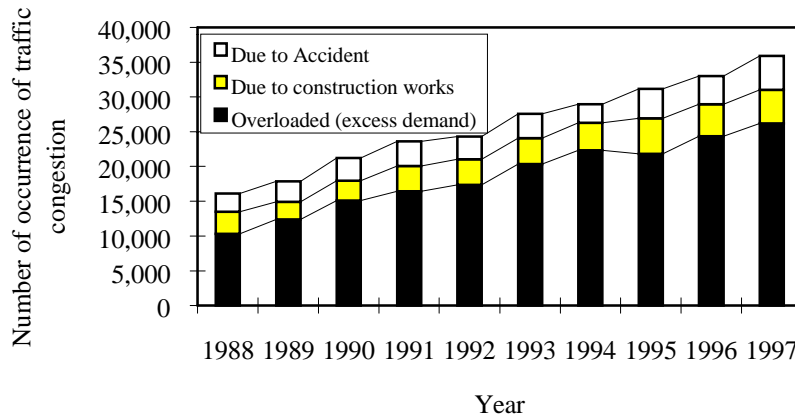


FIGURE 1 Number of occurrences of traffic congestion.

in Figure 1. The congestion due to excess demand (overloaded) occurred as much as approximately 36,000 in the year of 1997.

As shown in Figure 2, which represents share of bottlenecks by section and congestion quantity (duration * length of congestion), approximately 50 percent of congestion due to excess demand happen at sags and tunnel entrances.

In order to alleviate traffic congestion in Japan, which is caused at limited locations as mentioned above, it is necessary to take swift actions, including the improvement of road network, the addition of lanes, and traffic demand management. The most urgent task for this is to grasp the capacity of existing expressways. Based on these backgrounds, and focusing on locations with frequent traffic congestion (19 bottlenecks), the authors estimated the traffic volumes just before and during congestion, proposed a capacity which considers the probability of the occurrence of traffic congestion, and carried out related factor analyses: the huge amount of data used for these calculations and analyses were collected for a period of approximately one year.

This report covers a part of these studies—the traffic volume just before the occurrence of traffic congestion and the results of the factor analyses.

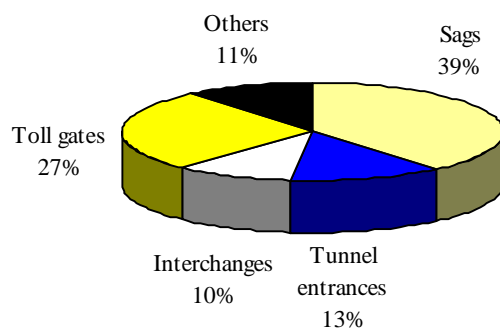


FIGURE 2 Share of bottlenecks by section and congestion quantity.

2. DESIGN CONCEPT AND STUDIES ON THE CAPACITY OF EXPRESSWAY SECTIONS IN JAPAN

In Japan, several studies on traffic volume have been conducted in parallel with expanding of expressway network, and the results of which were reflected in the Road Structure Ordinance (1982). However, Japanese standards related to highway capacity are mostly based on the HCM (*Highway Capacity Manual*, 1965) of the United States.

Previous studies on traffic capacity based on traffic survey data revealed the following findings with respect to traffic volume on expressways:

- The traffic volume of two-lane sections and that of three-lane basic sections on Tomei Expressway were approximately 3,700 to 4,000 vehicles/hour/direction and 5,500 vehicles/hour/direction, respectively (EHRF, 1978, 1982).
- The capacity of the tunnel sections on Tomei Expressway and that of Meishin Expressway were 3,000 to 3,200 vehicles/hour/two lanes, and 3,000 to 3,500 vehicles/hour/two lanes, respectively (Japan Highway Public Corporation, 1988).
- The capacity of sags on Tomei Expressway was 3,500 to 3,700 vehicles/hour/two lanes (Katakura, 1992).

Furthermore, the following findings were also obtained:

- Capacity sharply decreases at sags and tunnel entrances, since vehicles tend to slow down and change lanes at such locations. When a traffic congestion occurs at such locations, drivers lose alertness and are inclined to follow the speed of the surrounding traffic, which leads to a further reduction in speed and causes a congestion in the following traffic flow as well (Koshi, 1992).
- Congestion is likely to occur at sags which are difficult to be identified as such due to the road structure (e.g. sags with gentle longitudinal gradient differences) (Koshi and Oguchi, 1995; Oguchi, 1995).

To date, most of studies on traffic volume in Japan, including the above captioned, have been remaining in the evaluation of the measurement data with respect to the relationship between the capacity and speed or lane occupancy rate at designated locations, and the results of the studies have not been systematically integrated like the HCM. This paper therefore discusses the capacity, which were not verified by previous studies, based on recently obtained data and to classify the results in a systematic way.

3. TRAFFIC VOLUME AT BOTTLENECK SECTIONS

3.1 Traffic Volume at Bottleneck Sections

Three types of traffic volumes at bottleneck sections can be estimated by using data from traffic volume survey: the maximum traffic volume, traffic volume just before congestion, and traffic volume during congestion. The maximum traffic volume is the maximum

annual traffic volume at a bottleneck section and is considered as an incidentally observed traffic volume. The traffic volume during congestion is the average discharging volume during a period from the occurrence to the end of traffic congestion. The traffic volume just before congestion can be considered close to the possible capacity of the bottleneck sections. In this paper, 15-min traffic flow rate just before 5-min average speed falls less than 40 km/h is employed for this volume, since the analysis based on the flow rate per 5 minutes could overestimate the effects of an incidental high traffic volume recorded during a shorter period, and the analysis based on the hourly traffic volume cannot reflect traffic flow fluctuation.

The relationship between the traffic volume just before congestion and the traffic volume during congestion is shown in Figure 3.

3.2 Analysis Method

Prior to analysis on the capacity of bottleneck sections (sags and tunnel entrances), traffic volume analysis was carried out on 19 sections with congestion frequencies of more than 10 times/year and average congestion lengths of more than 2 km. The data used in the traffic volume analysis are the traffic volume of each direction; the traffic volume of each lane; the traffic volume of each type of vehicle; and the average vehicle speed, all of which were recorded every five minutes by vehicle detectors embedded in expressway lanes at intervals of approximately 2 km. The vehicle detectors identify vehicles with lengths of less than 5.5 m as small vehicles and those with lengths of 5.5 m or longer as heavy vehicles: the percentage of heavy vehicles was calculated based on this identification.

In order to correctly evaluate the conditions of traffic congestion, detectors installed at immediately upstream of bottleneck sections were selected for data collection, since no vehicle detectors at surveyed bottleneck sections had been placed at the beginning points of congestion. Unusual data due to the malfunction of the detectors and data on congestion due to construction activities or accidents were excluded from the analysis.

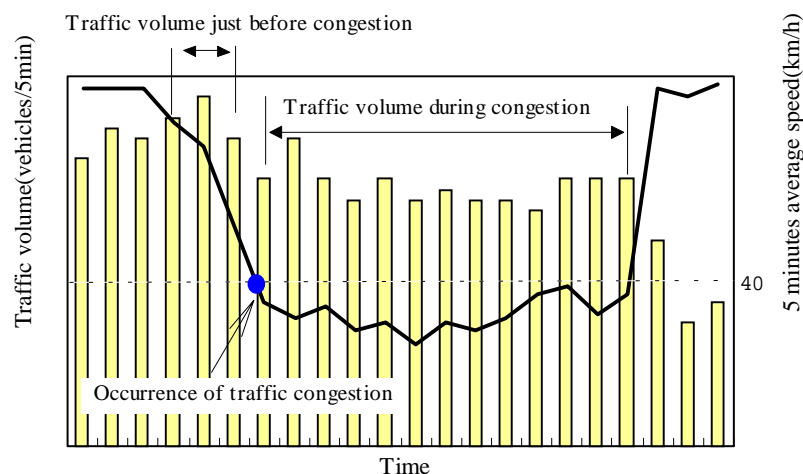


FIGURE 3 Relationship between the traffic volume before congestion and traffic volume during congestion.

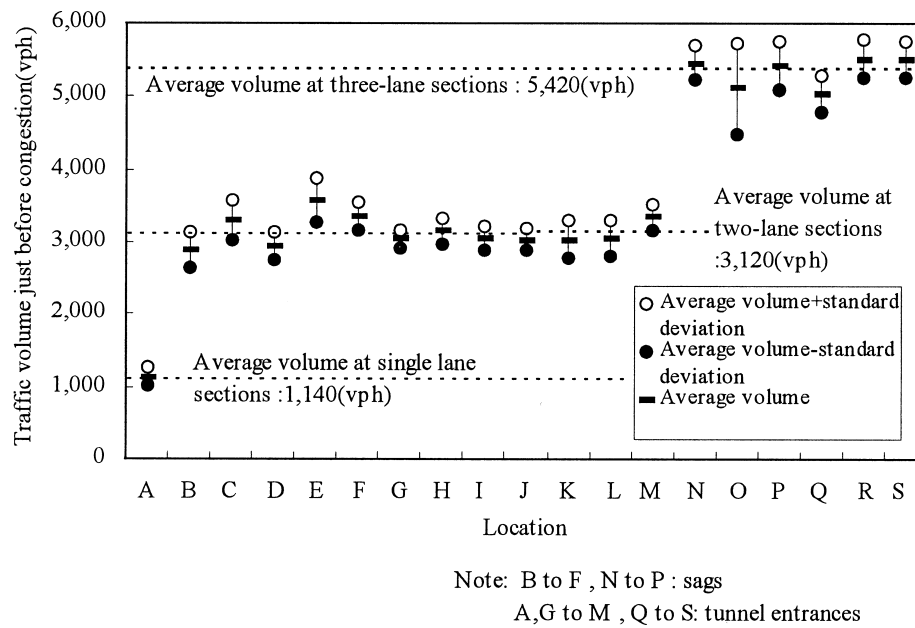


FIGURE 4 Traffic volumes before congestion by number of lanes.

3.3 Traffic Volume Just Before Congestion

Figure 4 shows the calculation results of traffic volume for 19 bottlenecks just before congestion. As shown in this figure, the traffic volumes of bottleneck sections vary a great deal.

Table 1 compares the traffic volumes just before congestion according to the number of lanes, which are calculated by applying the weighted average method on the number of samples: the maximum traffic volume and the traffic volume during congestion at bottle neck sections are also shown for reference in the table.

TABLE 1 Summary of Traffic Volume Just Before Congestion and Maximum Traffic Volume and Traffic Volume During Congestion

Number of lanes	Traffic volume just before congestion (vph)	Maximum traffic volume (vph)	Traffic volume during congestion (vph)	Number of bottlenecks	Number of observation
1	1,140	1,352	960	1	25
2	3,120	3,620	2,770	12	456
3	5,420	5,940	4,770	6	240

4. FACTOR ANALYSIS ON TRAFFIC VOLUME JUST BEFORE CONGESTION

The HCM as well as Japanese “Traffic Capacity of Road” (Japan Road Association, 1984) indicates that the results of factor analyses on highway capacity are mainly influenced by the following factors:

- Number of lanes
- Lateral clearance
- Percentage of heavy vehicles
- Longitudinal gradient
- Driver characteristics

Taking into consideration the above, analyses were conducted on the relationship between the traffic volume just before congestion and the number of lanes, the lateral clearance, the longitudinal gradient, the percentage of heavy vehicles, and the day of the week: the statistical hypothesis testing was conducted for the analyses and the results are given in the following sections.

4.1 Number of Lanes

Figure 5 shows the traffic volume per lane just before congestion. This figure shows that the traffic volume just before congestion is considerably influenced by the number of lanes: the capacity per lane increases more than proportionally to the increment of lanes.

4.2 Lateral Clearance (Width of Left Side Shoulder)

Figure 6 shows the relationship between the width of left side shoulder and the traffic volume just before congestion. The results of the statistical hypothesis testing showed that a significant difference is obtained only for three-lane tunnels when the significance level is 0.01. It is considered that the effect of shoulder width on traffic volume just before congestion are less prominent in the range of 0.3 m to 2.5 m in left side shoulder length. The traffic volume of three-lane tunnels with a shoulder width of 1.0 m is larger than that of three-lane tunnels with a shoulder width of 2.5 m. This is probably because of the difference of the cross sectional shape of tunnels, therefore further study is needed.

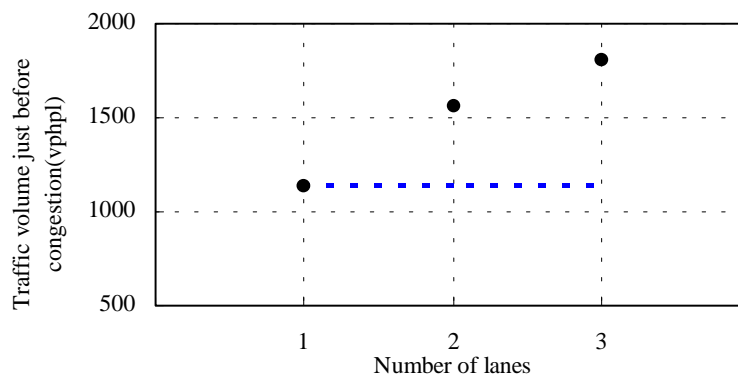


FIGURE 5 Traffic volume per lane before congestion.

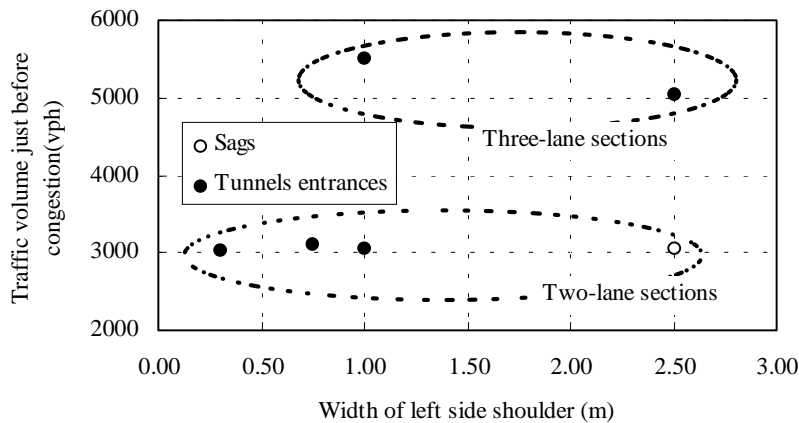


FIGURE 6 Relationship between the width of left side shoulder and traffic volume before congestion.

4.3 Longitudinal Gradient

The relationship between the longitudinal gradient and the traffic volume just before congestion is shown in Figure 7: in this figure, the longitudinal gradient of the downstream portion of a sag curve is used as the longitudinal gradient of a sag section. The results of the statistical hypothesis testing showed that a significant difference is obtained only for two-lane sags when the significance level is 0.01. Although the traffic volume at sags could be influenced by the longitudinal gradients, the certain tendency is not found between the longitudinal gradient and the traffic volume.

Focusing on sag sections, Figure 8 shows the relationship between the longitudinal gradient difference and the traffic volume just before congestion. The statistical hypothesis testing revealed that a significant difference appears for two-lane sags, but not for three-lane ones, when the significance level is 0.01. Although the traffic volume at sags could be influenced by the longitudinal gradient difference, the certain tendency between the longitudinal gradient difference and the traffic volume is not revealed.

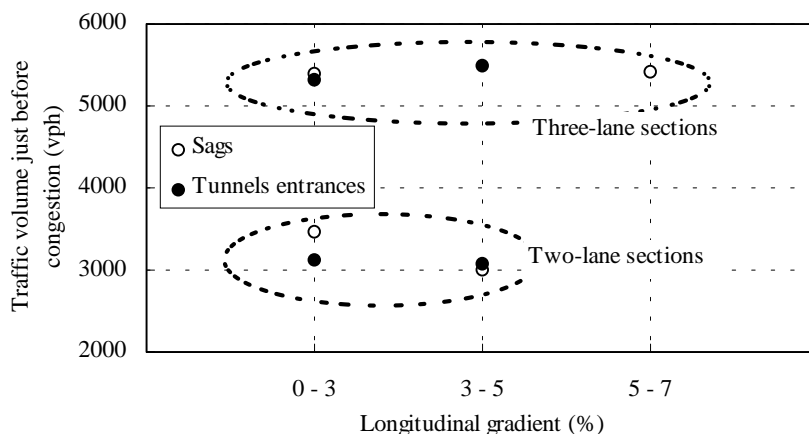


FIGURE 7 Relationship between longitudinal gradient and the traffic volume before congestion.

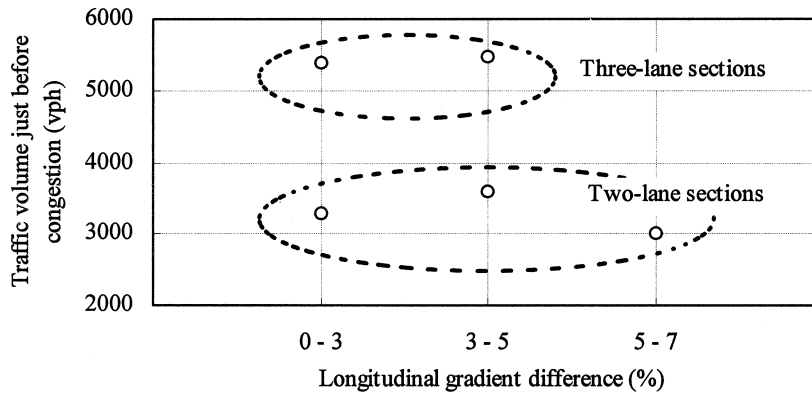


FIGURE 8 Relationship between longitudinal gradient difference and the traffic volume before congestion.

4.4 Percentage of Heavy Vehicles

Figure 9 shows the relationship between the percentage of heavy vehicles and the traffic volume just before congestion: the term “heavy vehicles” here means those with lengths of more than 5.5 m.

The statistical hypothesis testing showed that where the significance level is 0.01, a significant difference appears for sags other than those with three lanes in the traffic volumes for two-lane sags, two-lane tunnels and three-lane tunnels, the certain tendency were not found. Therefore it is considered the effect of the percentage of heavy vehicles is less prominent.

4.5 Effects of the Day of the Week

The relationship between the day of the week (weekdays, Saturdays, holidays) and the traffic volume just before congestion is shown in Figure 10. It was found that where the significance level is 0.01, the significant difference appears only for two-lane sags. With respect to the traffic volumes for two-lane sags, the result is: volume for weekdays > volume for Sundays and holidays or Saturdays. This result might have been influenced by the driver characteristics.

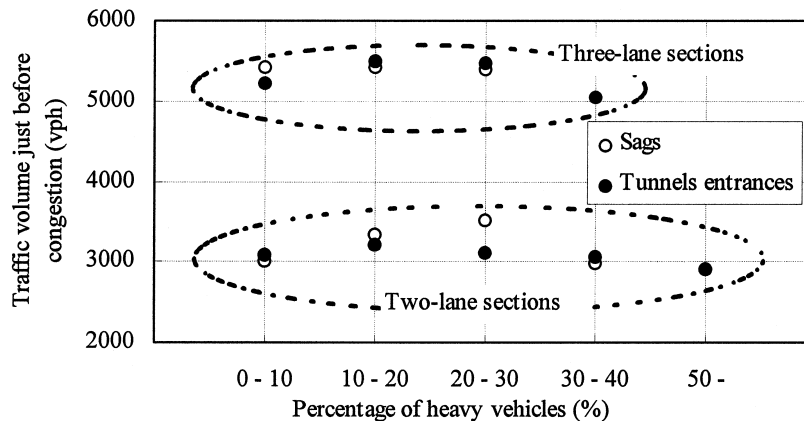


FIGURE 9 Relationship between the percentage of heavy vehicles and the traffic volume immediately before congestion.

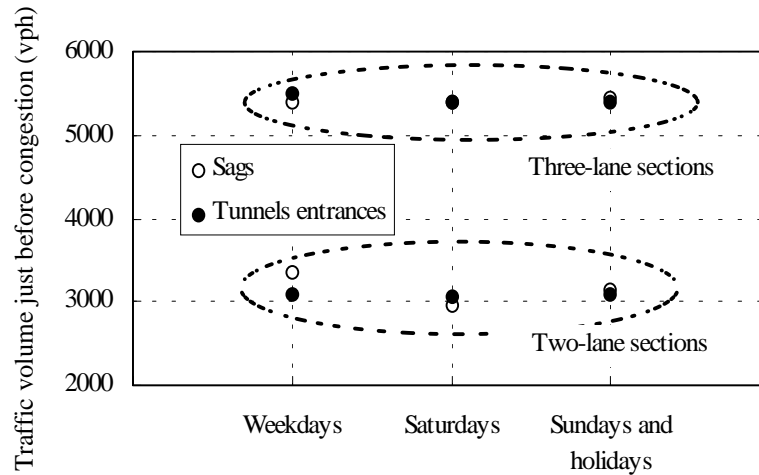


FIGURE 10 Relationship between the day of the week (weekdays, Saturdays, holidays) and the traffic volume before congestion.

5. CONCLUSIONS

The authors estimated three types of traffic volume at bottleneck sections (i.e., the traffic volume just before congestion, the maximum traffic volume, and the traffic volume during congestion) based on the data which were collected through a long-term survey (approximately one year) at bottleneck sections on the basic expressway sections (e.g., sags and tunnel entrances). Focusing on the traffic volume just before congestion, the authors also conducted factor analysis in order to verify the relationship between the traffic volume just before congestion and the number of lanes; the width of left side shoulder; the longitudinal gradient; the percentage of heavy vehicles; and the day of the week.

As a result, the following findings were obtained:

- The traffic volume just before congestion is dependent on the number of lanes: the capacity per lane increases more than proportionally to the increment of the number of lanes.
- The traffic volume just before congestion is not prominently influenced by the left side shoulder width in the range, 0.3 m to 2.5 m.
- The traffic volume just before congestion tends to be influenced by the longitudinal gradient or the longitudinal gradient difference, the effects are not revealed in this study.
- The traffic volumes just before congestion is not prominently influenced by the percentage of heavy vehicles.
- The traffic volume of two-lane sags just before congestion tends to vary depending on the day of the week. This is particularly related to the driver characteristics.

The analyses this time revealed the traffic characteristics at sags, tunnel entrances, and those locations with a traffic volume of close to the maximum capacity, which were not covered by such manuals as the HCM. The traffic characteristics were obtained based on the conditions that there exist a lot of tunnels and sags in Japan due to its topographical features; that the maximum number of lanes of expressways is three for each direction; that traffic congestion more frequently occurs in Japan than other countries; and that length of heavy vehicles is defined as more than 5.5 m. However the findings obtained by the study this time are expected to give useful suggestions for studies in foreign countries.

Based on the results mentioned above, the authors will continue to conduct studies to propose appropriate capacity for expressways in Japan.

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